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DESCRIPTION

IMPELLER FOR COMPRESSOR

TECHNICAL FIELD

[0001]

The present invention relates to an impeller for a centrifugal compressor or a mixed-flow compressor, for example, an impeller for a centrifugal compressor or a mixed-flow compressor employed in an aeronautical gas turbine, a marine supercharger, a motor vehicle supercharger, and the like.

BACKGROUND ART

[0002]

Up to now, the surface of the hub of impellers employed in centrifugal compressors and mixed-flow compressors has not been the focus of much research, and improvements have not been made to the surface of the impeller hub (see for example, Patent Document 1).

Patent Document 1: Japanese Unexamined Patent Application, First Publication No. Sho 55-35173

DISCLOSURE OF INVENTION

[0003]

ATTACHMENT B

The inventors of the present application have therefore focused on research on the surface of the hub of the rotating impeller, and as a result, have become aware of the occurrence of the following phenomenon on the hub surface.

For example, in an impeller 100 of a centrifugal compressor shown in FIG. 14A, when the velocity of rotation about the axis of rotation C is imparted to the flow entering from the impeller inlet 10, by blades 11 of the impeller 100, a centrifugal force F1 acts upon this flow. This centrifugal force F1 can be resolved into components in a direction perpendicular to the hub surface 12c and in a direction orthogonal to this perpendicular direction. A force F2 acting in the direction perpendicular to the hub surface 12c acts in a direction separating the flow from the hub surface 12c, and thus, it is known that the boundary layer is enlarged (or in extreme cases the flow is reversed in the proximity of the hub, or the flow is separated from the hub surface 12c), thereby increasing losses in the interior of the impeller, and inviting a reduction in the efficiency of the centrifugal compressor 100.

Since at the impeller outlet 102, the direction of the centrifugal force F1 and the direction of the tangent to the hub surface 12c are the same (that is to say, the force

F2 acting in the direction perpendicular to the hub surface is zero), the force acting to separate the flow from the hub surface 12c disappears.

Furthermore, reference symbols 12, 12a, 12b, LE, TE, and B in the figure illustrate respectively the hub, the minor diameter of the hub, the major diameter of the hub, the leading edge of the blade 11, the trailing edge of the blade 11, and the region of marked enlargement of the boundary layer (that is to say, the region in which the thickness of the boundary layer is markedly increased).

[0004]

Moreover, the same phenomenon also occurs in the mixed-flow compressor impeller 200 shown in FIG. 14B. Particularly with mixed-flow compressors, since the force F2 tending to separate the flow from the hub surface 12c acts up to the impeller outlet 102 where the hub surface 12c is inclined, it is known that distortion of flow velocity remains due to enlargement of the boundary layer up to the impeller outlet 102, and losses at the impeller outlet 102 increase, inviting a reduction in efficiency of the mixed-flow compressor 200.

[0005]

With the foregoing in view, it is an object of the present invention to improve the efficiency of the compressor by preventing localized concentration of the

boundary layer occurring on the surface of the hub, and by inducing a reduction in the thickness of the boundary layer.

[0006]

In the present invention, the following means have been adopted to solve the aforementioned problems.

The compressor impeller according to the present invention has a plurality of blades, and a hub disposed at the root of this plurality of blades, and at least part of the surface of the hub on which a fluid flows is inclined in relation to an axis of rotation, and a boundary layer reduction part which induces a reduction in the thickness of a boundary layer occurring due to a flow of fluid, is provided on the surface of the hub.

According to such a compressor impeller, localized concentration of the boundary layer formed on the surface of the hub is prevented by the boundary layer reduction part provided on the surface of the hub (hub surface), and the thickness of the boundary layer is thus reduced more than for impellers not having the boundary layer reduction part.

[0007]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part is provided at a position at which the centrifugal force

acting on the flow of fluid acts in a direction to separate the flow of fluid from the surface of the hub.

According to such a compressor impeller, a comparatively large centrifugal force acts, and the boundary layer reduction part is preferably provided on the surface of the hub inclined at an angle in relation to the axis of rotation of the impeller, that is to say, on the surface of the inclined hub separated a certain distance from the axis of rotation of the impeller.

[0008]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part is provided on the downstream side from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet.

According such a compressor impeller, the start point of the boundary layer reduction part is positioned at a position separated by a prescribed distance from the edge of the impeller inlet. That is to say, the boundary layer reduction part is not provided close to the edge of the inlet on the downstream side.

[0009]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part is

formed as a convex part projecting perpendicularly to the surface of the hub.

According to such a compressor impeller, a flow (hereafter referred to as "secondary flow") towards the flow path formed on the surface of the convex part, from the surface of the hub to the blades occurs due to the force (F2) acting perpendicularly to the surface of the hub. The boundary layer formed on the surface of the hub or on the surface of the convex part migrates in the direction of the flow path formed between the blades due to this secondary flow, and is dragged into the primary flow in the flow path, and is carried away downstream together with this primary flow.

[0010]

In the compressor impeller according to the present invention, preferably the convex part is provided as at least one small blade formed along the surface of the blade, between the blades.

According to such a compressor impeller, secondary flow occurs on the surface of the small blade which is formed so that primary flow is not hindered and losses are minimized, and which has a surface area greater than the convex part, and a greater portion of the boundary layer formed on the surface of the hub or on the surface of the

small blade is carried away downstream by the primary flow in the flow path.

[0011]

In the compressor impeller according to the present invention, preferably a height of the small blade is set at between approximately 1/10 and approximately 1/2 of the height of the blade.

According to such a compressor impeller, since the leading edge of the small blade is configured to enter the primary flow of fluid, the secondary flow occurring on the surface of the small blade is guided reliably and effectively within the primary flow passing between the blades, and the thickness of the boundary layer is further reduced.

[0012]

In the compressor impeller according to the present invention, preferably a maximum distance between the small blades is set so as to be greater than twice the thickness of the boundary layer occurring due to the flow of fluid, on the surface of the hub.

According to such a compressor impeller, the spacing of the small blades is formed so as to be greater than twice the thickness of the boundary layer occurring on the surface of the hub due to the flow of fluid, and the primary flow passes between small blade and small blade.

Therefore merging of the secondary flow occurring on the surface of the small blade, and the primary flow, is promoted and the thickness of the boundary layer is further reduced.

[0013]

The compressor impeller according to the present invention, is preferably a centrifugal compressor impeller, and the boundary layer reduction part is provided up to a position at which a force acting perpendicularly to the hub surface becomes zero.

According to such a compressor impeller, the boundary layer reduction part is provided at a location at which the centrifugal force acting on the flow of fluid acts in a direction to separate the flow of fluid from the surface of the hub, that is to say, the boundary layer reduction part is provided from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet, up to a position at which the force acting perpendicularly to the hub surface is zero. As a result, the thickness of the boundary layer formed close to the hub surface is reduced across the entire hub surface.

[0014]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part is

also extended downstream beyond a position at which the force acting perpendicularly to the hub surface is zero.

According to such a compressor impeller, since the boundary layer reduction part is also extended downstream beyond the position at which the force acting perpendicularly to the surface of the hub is zero, the boundary layer is discharged outwards in the radial direction of the impeller along the extended boundary layer reduction part, and the thickness of the boundary layer is further reduced.

[0015]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part is provided up to the edge of the impeller outlet.

According to such a compressor impeller, since the boundary layer reduction part is provided extended up to the edge of the impeller outlet, the boundary layer is discharged outwards in the radial direction of the impeller along the extended boundary layer reduction part, and the thickness of the boundary layer is further reduced.

Furthermore, since the fluid flowing out from the edge of the impeller outlet of the boundary layer reduction part reaches the diffuser provided downstream by the shortest path, losses due to flow velocity distortion of the fluid in the entire centrifugal compressor are reduced.

[0016]

The compressor impeller according to the present invention is preferably a mixed-flow compressor impeller, and the boundary layer expansion prevention part is provided up to the edge of the outlet of the impeller.

According to such a compressor impeller, the boundary layer reduction part is provided at a location at which the centrifugal force acting on the flow of fluid acts in a direction to separate the flow of fluid from the surface of the hub, that is to say, the boundary layer reduction part is provided from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet, up to the edge of the impeller outlet. As a result the thickness of the boundary layer formed close to the hub surface is reduced across the entire hub surface.

[0017]

The compressor impeller according to the present invention has a plurality of blades, and a hub disposed at the root of this plurality of blades, and at least part of the surface of the hub on which a fluid flows is inclined in relation to an axis of rotation, and a boundary layer expansion prevention part which prevents expansion of a boundary layer occurring due to a flow of fluid, may be provided on the surface of the hub.

According to such a compressor impeller, expansion of the boundary layer formed on the surface of the hub is prevented by the boundary layer expansion prevention part provided on the surface of the hub (hub surface), and the thickness of the boundary layer is reduced in comparison to an impeller not having a boundary layer expansion prevention part.

Examples of compressors furnished with impellers having at least part of the surface of the hub on which the fluid flows inclined in relation to the axis of rotation, are centrifugal compressors and mixed-flow compressors.

[0018]

In the compressor impeller according to the present invention, preferably the boundary layer expansion prevention part is provided at a position at which the centrifugal force acting on the flow of fluid acts in a direction to separate the flow of fluid from the surface of the hub.

According to such a compressor impeller, a comparatively large centrifugal force acts, and the boundary layer expansion prevention part is provided on the surface of the hub having an inclination angle in relation to the axis of rotation of the impeller, that is to say, on the inclined surface of the hub separated a certain distance from the axis of rotation of the impeller.

[0019]

In the compressor impeller according to the present invention, preferably the boundary layer expansion prevention part is provided on the downstream side from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet.

According to such a compressor impeller, the start point of the boundary layer expansion prevention part is positioned at a position separated by a prescribed distance from the edge of the impeller inlet. That is to say, the boundary layer expansion prevention part is not provided close to the edge of the inlet on the downstream side.

[0020]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part comprises a plurality of grooves.

According to such a compressor impeller, the flow along the hub surface close to the hub surface passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, so that the flow close to the hub surface becomes turbulent.

[0021]

In the compressor impeller according to the present invention, preferably the plurality of grooves are formed linearly along the surface of the blades, between the blades.

According to such a compressor impeller, the flow along the hub surface close to the hub surface passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, so that turbulence occurs in the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of the flow is prevented.

[0022]

In the compressor impeller according to the present invention, preferably the linear grooves are divided into a plurality of regions between upstream and downstream.

According to such a compressor impeller, the flow along the hub surface close to the hub surface passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, so that turbulence occurs in the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented.

[0023]

In the compressor impeller according to the present invention, preferably the plurality of grooves are formed in a wave-shape in plan view, between the blades.

According to such a compressor impeller, the angle between the peak of a groove and the direction with which the flow passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, can be increased in some parts. Therefore strong turbulence occurs at these parts due to the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is further prevented.

[0024]

In the compressor impeller according to the present invention, preferably the plurality of grooves are formed in a sawtooth-shape in plan view, between the blades.

According to such a compressor impeller, the angle between the peak of a groove and the direction with which the flow passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, can be increased in some parts, and these parts can be formed in greater number. Therefore strong turbulence occurs due to the flow along the hub surface

close to the hub surface, and expansion of the boundary layer or separation of flow is further prevented.

[0025]

In the compressor impeller according to the present invention, preferably the plurality of grooves comprise a plurality of grooves formed between blades from one blade to another blade, so as to intersect diagonally with the flow path, and a plurality of grooves formed so as to intersect with these grooves, and formed from the other blade to the one blade, so as to intersect diagonally with the flow path.

According to such a compressor impeller, a plurality of projections are formed, and the flow along the hub surface close to the hub surface collides with these projections, or passes over these projections and flows into the trough of the adjacent groove, or passes over these projections and proceeds diagonally towards the top of the adjacent groove, so that strong turbulence occurs in the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented.

[0026]

In the compressor impeller according to the present invention, preferably the plurality of grooves are formed

concentrically with the axis of rotation of the impeller, between the blades.

According to such a compressor impeller, all flow along the hub surface close to the hub surface passes over the peak of a groove and flows into the trough of the adjacent groove, or passes over the peak of a groove and proceeds diagonally towards the top of the adjacent groove, so that strong turbulence occurs due to the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented.

[0027]

In the compressor impeller according to the present invention, preferably the boundary layer reduction part comprises a plurality of concave and convex parts.

According to such a compressor impeller, the flow along the hub surface close to the hub surface collides with these convex parts, or passes over these convex parts and flows into the adjacent concave part, or passes over these convex parts and proceeds diagonally towards the top of the adjacent convex or concave part, so that strong turbulence occurs due to the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented.

[0028]

In the compressor impeller according to the present invention, preferably the plurality of concave and convex parts are circular-shaped in plan view.

According to such a compressor impeller, the concave and convex parts are formed in the hub surface in readily manufactured hemispherical shapes.

[0029]

In the compressor impeller according to the present invention, a maximum depth of the grooves or the concave and convex parts is preferably between 0.3% and 2.0% of the outside diameter of the impeller, and more preferably between 0.5% and 2.0%.

According to such a compressor impeller, for example, if the outside diameter of the impeller is 100 mm, the grooves are formed to a maximum depth of between 0.3 mm and 2.0 mm, and more preferably to between 0.5 mm and 2.0 mm, and are formed deeper and wider than grooves being machining tracks remaining on the hub surface of the impeller manufactured by milling (generally having a width and maximum depth of approximately 0.2% of the outside diameter of the impeller).

[0030]

Preferably the compressor impeller according to the present invention is a centrifugal compressor impeller, and the boundary layer expansion prevention part is provided up

to a position at which a force acting perpendicularly to the hub surface is zero.

According to such a compressor impeller, the boundary layer expansion prevention part is provided at a location at which the centrifugal force acting on the flow of fluid acts in a direction separating the flow of fluid from the surface of the hub, that is to say, the boundary layer expansion prevention part is provided from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet, up to a position at which the force acting perpendicularly to the hub surface is zero. Therefore turbulence occurs in the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented over the entire hub surface.

[0031]

Preferably the compressor impeller according to the present invention is a mixed-flow compressor impeller, and the boundary layer expansion prevention part is provided up to the edge of the outlet of the impeller.

According to such a compressor impeller, the boundary layer expansion prevention part is provided at a location at which the centrifugal force acting on the flow of fluid acts in a direction separating the flow of fluid from the

hub surface, that is to say, the boundary layer expansion prevention part is provided from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, from the edge of the impeller inlet, to the edge of the outlet. Therefore turbulence occurs in the flow along the hub surface close to the hub surface, and expansion of the boundary layer or separation of flow is prevented over the entire hub surface.

[0032]

The compressor according to the present invention is furnished with one of the aforementioned impellers.

According to such a compressor, this is furnished with an impeller provided with a boundary layer reduction part which prevents localized concentration of the boundary layer generated on the surface of the hub, and reduces boundary layer thickness, or an impeller having a boundary layer expansion prevention part which prevents expansion of the boundary layer formed on the surface of the hub.

[0033]

According to the present invention, the following effects are demonstrated.

By means of the boundary layer reduction part, localized concentration of the boundary layer generated on the surface of the hub can be prevented and boundary layer thickness can be reduced.

Moreover, by employing an impeller provided with a boundary layer reduction part, localized concentration of the boundary layer can be prevented, and also boundary layer thickness can be reduced, losses within the impeller can be reduced, and compression efficiency of the compressor can be improved,.

By means of the boundary layer expansion prevention part, turbulence in the flow along the hub surface close to the hub surface can be generated, and expansion of the boundary layer or separation of flow can be prevented.

Furthermore, by employing an impeller provided with a boundary layer expansion prevention part, losses within the impeller can be reduced, and compression efficiency of the compressor can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034]

FIG. 1A through C are diagrams showing a first embodiment of an impeller according to the present invention, wherein FIG. 1A is a perspective view of the main parts, FIG. 1B is a cross-sectional view on I-I in FIG. 1A, and FIG. 1C is a cross-sectional view on II-II in FIG. 1A.

FIG. 2A and B are diagrams showing a second embodiment according to the present invention, wherein FIG. 2A is a

perspective view of the main parts, and FIG. 2B is a cross-sectional view on III-III in FIG. 2A.

FIG. 3 is a perspective view of the main parts showing a third embodiment of the impeller according to the present invention.

FIG. 4 is a perspective view of the main parts showing a fourth embodiment of the impeller according to the present invention.

FIG. 5 is a perspective view of the main parts showing a fifth embodiment of the impeller according to the present invention.

FIG. 6A and B are diagrams showing the fifth embodiment of the impeller according to the present invention, wherein FIG. 6A is a cross-sectional view on a-a in FIG. 5, and FIG. 6B is a cross-sectional view on b-b in FIG. 5.

FIG. 7 is a perspective view of the main parts showing a sixth embodiment of the impeller according to the present invention.

FIG. 8A and B are diagrams showing a seventh embodiment of the impeller according to the present invention, wherein FIG. 8A is a perspective view of the main parts, and FIG. 8B is a plan view of a boundary layer expansion prevention part.

FIG. 9A and B are diagrams showing an eighth embodiment of the impeller according to the present invention, wherein FIG. 9A is a perspective view of the main parts, and FIG. 9B is a plan view of a boundary layer expansion prevention part.

FIG. 10A and B are diagrams showing a ninth embodiment of the impeller according to the present invention, wherein FIG. 10A is a perspective view of the main parts, and FIG. 10B is a cross-sectional view on c-c in FIG. 10A.

FIG. 11 is a perspective view of the main parts showing a tenth embodiment of the impeller according to the present invention.

FIG. 12A and B are diagrams showing an eleventh embodiment of the impeller according to the present invention, wherein FIG. 12A is a perspective view of the main parts, and FIG. 11B is a cross-sectional view on d-d in FIG. 12A.

FIG. 13A and B are similar to FIG. 6B, and show another cross-sectional shape for the grooves being the boundary layer expansion prevention part.

FIG. 14A and B are diagrams for explaining problems of a conventional impeller, wherein FIG. 14A is a cross-sectional view of a centrifugal compressor impeller, and FIG. 14B is a cross-sectional view of a mixed-flow compressor impeller.

BEST MODE FOR CARRYING OUT THE INVENTION

[0035]

A first embodiment of an impeller for a compressor according to the present invention is described below with reference to FIG. 1A through FIG. 1C. The impeller of the present embodiment is a specific example of application to a centrifugal compressor.

FIG. 1A is a perspective view of the main parts of an impeller 10 according to the present embodiment, with the edge on the inlet side of the impeller 10 omitted. Moreover FIG. 1B is a cross-sectional view on I-I in FIG. 1A, and FIG. 1C is a cross-sectional view on II-II in FIG. 1A.

[0036]

As shown in FIG. 1A through FIG. 1C, the impeller 10 according to the present embodiment comprises a plurality of blades 11, and a hub 12 disposed at a root R of this plurality of blades 11, as the primary elements.

Each blade 11 is provided so that the leading edge LE is positioned at the minor diameter end 12a of the hub 12, and the trailing edge TE is positioned at the major diameter end 12b of the hub 12 (see FIG. 14A).

[0037]

For example, three small blades are provided in a region on the hub surface 12c in which the centrifugal force F1 (see FIG. 14A) acts perpendicularly to the hub surface 12c, for example, a region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side (the upstream-most position of the small blade 13a positioned at the center in FIG. 1A (the start point)), to a position at which the force F2 acting perpendicularly to the hub surface 12c is zero (the downstream-most position of the small blades 13a and 13b in FIG. 1A (the end point)), and in which the small blades (boundary layer reduction part; convex parts) 13a and 13b are along the surface of the blade 11 (or the root R of the blades 11) in a region positioned between the blades 11.

[0038]

As shown in FIG. 1A, of these three small blades 13a and 13b, the small blade 13a positioned at the center (that is to say, the small blade positioned in the middle), is provided in the region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side, to a position at which the force F2 acting perpendicularly to the hub surface 12c is zero, and approximately midway between the blades 11.

Furthermore, the small blades 13b positioned at both sides of the small blade 13a are provided in the region from a position approximately 1/2 of the distance from the edge of the impeller inlet to the edge of the outlet on the inlet side, to a position at which the force F2 acting perpendicularly to the hub surface 12c is zero, and approximately midway between the blade 11 and the small blade 13a.

[0039]

As shown in FIG. 1B and FIG. 1C, the cross-sectional shape of these small blades 13a and 13b becomes gradually thinner as the distance from the hub surface 12c increases. Moreover, the leading edges and trailing edges of these small blades 13a and 13b also become gradually thinner towards the upstream and downstream ends.

[0040]

A height h of these small blades 13a and 13b (that is to say, the minimum distance from the hub surface 12c to the tip of the small blades 13a and 13b) is between approximately 1/10 and approximately 1/2 of a height of the blade 11 at the same radial position.

A space W between the small blades 13a and 13b (that is to say, the minimum distance between the tip of the small blade 13a and the tip of the small blade 13b) is

greater than twice a thickness δ of a boundary layer BL occurring on the hub surface 12c due to the flow of fluid.

[0041]

By providing the small blades 13a and 13b in this manner along the surface of the blade 11 in the region in which the centrifugal force F1 (see FIG. 14A) of the hub surface 12c acts perpendicularly to the hub surface 12c, a secondary flow occurs in a direction approximately perpendicular to the hub surface 12c (the direction of the arrows in the diagram) on the surfaces of the small blades 13a and 13b. The boundary layer BL on the hub surface 12c and the small blades 13a and 13b is dragged into (onto) the secondary flow and is guided into the flow path formed between the blades 11, that is to say, is guided in the direction of the primary flow of fluid passing between the blades 11, and finally merges with the primary flow of fluid and flows downstream. Therefore localized concentration of the boundary layer BL can be prevented, and the thickness δ of the boundary layer BL can be reduced.

Moreover, the height h of the small blades 13a and 13b is between approximately 1/10 and approximately 1/2 of the height of the blade 11 at the same radial position. Therefore the secondary flow occurring on the surface of the small blades 13a and 13b can be guided reliably and effectively into the primary flow passing between the

blades 11, and the thickness δ of the boundary layer BL can be further reduced.

Furthermore, the space W between the small blades 13a and 13b is greater than twice the thickness δ of the boundary layer BL occurring on the hub surface 12c due to the flow of fluid, and is such that the primary flow of fluid passes between the small blades 13a and 13b. Therefore merging of the secondary flow occurring on the surface of the small blades 13a and 13b, and the primary flow of fluid is accelerated, and the thickness δ of the boundary layer BL can be even further reduced.

Moreover, the leading edges and trailing edges of the small blades 13a and 13b become gradually thinner towards the upstream and downstream ends. Therefore vortex losses occurring when the primary flow of fluid collides with the leading edges of the small blades 13a and 13b, or when the primary flow of fluid separates from the trailing edges of these small blades 13a and 13b, can be minimized.

Furthermore, the tips of the small blades 13a and 13b become gradually thinner as the distance from the hub surface 12c increases. Therefore vortex losses occurring when the secondary flow occurring on the surface of the small blades 13a and 13b separates from the leading edges of the small blades 13a and 13b can be minimized.

[0042]

A second embodiment of the impeller for a compressor according to the present invention is described using FIG. 2A and FIG. 2B. FIG. 2A is a similar diagram to FIG. 1A, with the edge on the inlet side of the impeller 20 omitted. Moreover FIG. 2B is a cross-sectional view on III-III in FIG. 2A.

In the impeller 20 of the present embodiment, all the start points of the small blades 23 being the boundary layer reduction part (convex parts), are provided at the same position as the start point of the small blade 13a of the first embodiment, and all end points of the small blades 23 are further downstream than the end points of the small blades 13a and 13b of the first embodiment. That is to say, the present embodiment differs from the first embodiment in that the end points are provided extended towards the edge of the outlet. Since other elements of the configuration are the same as for the first embodiment, a description of these elements of the configuration is omitted here, and only the small blades 23 are described.

Components in common with the first embodiment are labeled with the same reference symbols.

[0043]

For example, three small blades 23 are provided in a region on the hub surface 12c from a position approximately 1/4 of the distance from the edge of the impeller inlet to

the edge of the outlet, on the inlet side (the upstream-most position of the small blades 23 in FIG. 2A (the start point)), to a position approximately 1/5 of the distance from the edge of the impeller inlet to the edge of the outlet, on the outlet side (the downstream-most position of the small blades 23 in FIG. 2A (the end point)), and along the surface of the blade 11 (or the root R of the blade 11) in a region positioned between the blades 11.

[0044]

As in the first embodiment, the cross-sectional shape of these small blades 23 becomes gradually thinner as the distance from the hub surface 12c increases.

Moreover, as in the first embodiment, the leading edges and trailing edges of these small blades 23 also become gradually thinner towards the upstream and downstream ends (see FIG. 1B and FIG. 1C).

[0045]

As in the first embodiment, the height h of these small blades 23 (that is to say, the minimum distance from the hub surface 12c to the tip of the small blades 23) is between approximately 1/10 and approximately 1/2 of the height of the blade 11 at the same radial position.

Furthermore, as in the first embodiment, the space W between the small blades 23 and 23 (that is to say, the minimum distance between the tip of one small blade 23 and

the tip of the adjacent small blade 23) is greater than twice the thickness δ of the boundary layer BL occurring on the hub surface 12c due to the flow of fluid.

[0046]

Similar effects to the first embodiment can be obtained by providing these small blades 23.

Moreover, all start points of the small blades 23 are at a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side, that is to say, at the same position as the start point of the small blade 13a of the first embodiment. Therefore the surface area of the small blades 23 is increased beyond that of the first embodiment, and secondary flow is increased accordingly, concentration of the boundary layer BL can be further prevented, and the thickness δ of the boundary layer BL can be further reduced.

Furthermore, all end points of the small blades 23 are at a position approximately 1/5 of the distance from the edge of the impeller inlet to the edge of the outlet, on the outlet side, that is to say, are provided extended downstream (towards the outlet) beyond the end points of the small blades 13a of the first embodiment. Therefore the boundary layer BL is discharged outwards in the radial direction of the impeller 20 along the surface of these

extended small blades 23, and the thickness δ of the boundary layer can be even further reduced.

[0047]

A third embodiment of the impeller for a compressor according to the present invention is described using FIG. 3. FIG. 3 is a similar diagram to FIG. 1A and FIG. 2A, with the edge on the inlet side of the impeller 30 omitted.

The impeller 30 of the present embodiment differs from the second embodiment in that all end points of the small blades 33 being the boundary layer reduction part (convex parts), are provided extended to the edge of the outlet of the impeller 30. Since other elements of the configuration are the same as for the second embodiment, a description of these elements of the configuration is omitted here, and only the small blades 33 are described.

Components in common with the first and second embodiments are labeled with the same reference symbols.

[0048]

For example, three small blades 33 are provided in a region on the hub surface 12c from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side (the upstream-most position of the small blades 33 in FIG. 3 (the start point)) to the outlet edge, and along the surface of the

blade 11 (or the root R of the blade 11) in a region positioned between the blades 11.

[0049]

As in the first embodiment, the cross-sectional shape of these small blades 33 becomes gradually thinner as the distance from the hub surface 12c increases.

Moreover, as in the first embodiment, the leading edges and trailing edges of the small blades 33 also become gradually thinner towards the upstream and downstream ends (see FIG. 1B and FIG. 1C).

[0050]

As in the first embodiment, the height h of these small blades 33 (that is to say, the minimum distance between the hub surface 12c and the tip of the small blades 33) is between approximately 1/10 and approximately 1/2 of the height H of the blade 11 at the same radial position.

Furthermore, as in the first embodiment, the space W between the small blades 33 and 33 (that is to say, the minimum distance between the tip of one small blade 33 and the tip of the adjacent small blade 33) is greater than twice the thickness δ of the boundary layer BL occurring on the hub surface 12c due to the flow of fluid.

[0051]

Similar effects to the first embodiment can be obtained by providing these small blades 33.

Moreover, since all end points of the small blades 33 are provided extended to the edge of the impeller outlet, the boundary layer is discharged outwards in the radial direction of the impeller 30 along the surface of these extended small blades 33, and the thickness δ of the boundary layer can be even further reduced.

Furthermore, by providing all end points of the small blades 33 extended to the edge of the impeller outlet, the fluid flowing from the trailing edges of the small blades 33 reaches the diffuser provided downstream by the shortest path. Therefore losses due to distortion of flow velocity in the entire centrifugal compressor can be reduced.

[0052]

A fourth embodiment of the impeller for a compressor according to the present invention is described using FIG. 4. FIG. 4 is a similar diagram to FIG. 1A, FIG. 2A, and FIG. 3, with the edge on the inlet side of the impeller 40 omitted.

The impeller 40 of the present embodiment is applied to a mixed-flow compressor, and small blades similar to the small blades 13a and 13b serving as the boundary layer reduction part (convex parts) shown in FIG. 1A through FIG. 1C, are formed on the hub surface 12c.

[0053]

As shown in FIG. 4, the impeller 40 according to the present embodiment comprises a plurality of blades 11, and a hub 12 disposed at the root R of this plurality of blades 11, as the primary elements.

Each blade 11 is provided so that the leading edge LE is positioned at the minor diameter end 12a of the hub 12, and the trailing edge TE is positioned at the major diameter end 12b of the hub 12 (see FIG. 14B).

[0054]

For example, three small blades are provided in a region on the hub surface 12c in which the centrifugal force F1 (see FIG. 14B) acts perpendicularly to the hub surface 12c, for example, a region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side (the upstream-most position of the small blades in FIG. 4) (the start point)), to the edge of the impeller outlet (the downstream-most position of the small blades in FIG. 4 (the end point)), and in which the small blades 43a and 43b are along the surface of the blade 11 (or the root R of the blades 11) in a region positioned between the blades 11.

[0055]

As shown in FIG. 4, of these three small blades 43a and 43b, the small blade 43a positioned in the center (that is to say, the small blade positioned in the middle), is

provided in a region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side, to the edge of the impeller outlet, and approximately midway between the blades 11.

Furthermore, the small blades 43b positioned at both sides of the small blade 43a are provided in a region from a position approximately 1/2 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side, to the edge of the impeller outlet, and approximately midway between the blade 11 and the small blade 13a.

[0056]

As in the first embodiment, the cross-sectional shape of these small blades 43a and 43b becomes gradually thinner as the distance from the hub surface 12c increases.

Moreover, as in the first embodiment, the leading edges and trailing edges of the small blades 43a and 43b also become gradually thinner towards the upstream and downstream ends (see FIG. 1B and FIG. 1C.

[0057]

As in the first embodiment, the height h of these small blades 43a and 43b (that is to say, the minimum distance from the hub surface 12c to the tip of the small blades 43a and 43b) is between approximately 1/10 and

approximately 1/2 of the height of the blade 11 at the same radial position.

Furthermore, as in the first embodiment, the space w between the small blades 43a and 43b (that is to say, the minimum distance between the tip of the small blade 43a and the tip of the small blade 43b) is greater than twice the thickness δ of the boundary layer BL occurring on the hub surface 12c due to the flow of fluid.

[0058]

By providing the small blades 43a and 43b in this manner along the surface of the blade 11 in the region in which the centrifugal force F1 (see FIG. 14B) of the hub surface 12c acts perpendicularly to the hub surface 12c, a secondary flow occurs in a direction approximately perpendicular to the hub surface 12c (the direction of the arrows in FIG. 1A and FIG. 1B) on the surfaces of the small blades 43a and 43b. The boundary layer on the hub surface 12c and the small blades 43a and 43b is dragged into (onto) the secondary flow and is guided into the flow path formed between the blades 11, that is to say, is guided in the direction of the primary flow of fluid passing between the blades 11, and finally merges with the primary flow of fluid and flows downstream. Therefore localized concentration of the boundary layer BL can be prevented, and the thickness δ of the boundary layer BL can be reduced.

Moreover, the height h of the small blades 43a and 43b is between approximately 1/10 and approximately 1/2 of the height of the blade 11 at the same radial position. Therefore the secondary flow occurring on the surface of the small blades 43a and 43b can be guided reliably and effectively into the primary flow passing between the blades 11, and the thickness δ of the boundary layer BL can be further reduced.

Furthermore, the space W between the small blades 43a and 43b is greater than twice the thickness δ of the boundary layer BL occurring on the hub surface 12c due to the flow of fluid, and is such that the primary flow of fluid passes between the small blades 43a and 43b. Therefore merging of the secondary flow occurring on the surface of the small blades 43a and 43b, and the primary flow of fluid is accelerated, and the thickness δ of the boundary layer BL can be even further reduced.

Moreover, the leading edges and trailing edges of the small blades 43a and 43b become gradually thinner towards the upstream and downstream ends. Therefore vortex losses occurring when the primary flow of fluid collides with the leading edges of the small blades 43a and 43b, or when the primary flow of fluid separates from the trailing edges of the small blades 43a and 43b, can be minimized.

Furthermore, the tips of the small blades 43a and 43b become gradually thinner as the distance from the hub surface 12c increases. Therefore vortex losses occurring when the secondary flow occurring on the surface of the small blades 43a and 43b separates from the tips of the small blades 43a and 43b can be minimized.

[0059]

The present invention is not limited to the aforementioned embodiments, and for example, the start points of the small blades 43b shown in FIG. 4 can also be positioned at a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side as in FIG. 2A and FIG. 3.

The effects thus obtained have been described for the second embodiment, and a description is therefore omitted here.

[0060]

Moreover, the number of small blades is not limited to three, and any number is possible provided the primary flow between the small blades has a velocity.

[0061]

A fifth embodiment of the impeller for a compressor according to the present invention is described with reference to FIG. 5, and FIG. 6A and FIG. 6B. The impeller

of the embodiment described below is applied to a centrifugal compressor.

FIG. 5 is a perspective view of the main parts of an impeller 310 according to the present embodiment, and omits approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side. Furthermore, FIG. 6A is a cross-sectional view on a-a in FIG. 5, and FIG. 6B is a cross-sectional view on b-b in FIG. 5.

[0062]

As shown in FIG. 5, the impeller 310 according to the present embodiment comprises a plurality of blades 11, and a hub 12 disposed at the root R of this plurality of blades 11, as the primary elements.

Each blade 11 is provided so that the leading edge LE is positioned at the minor diameter end 12a of the hub 12, and the trailing edge TE is positioned at the major diameter end 12b of the hub 12 (see FIG. 14A).

[0063]

For example, a plurality of linear grooves (boundary layer expansion prevention part) 313 (five grooves in FIG. 5) along the surface of the blade 11 (or the root R of the blades 11) are provided in a region on the hub surface (surface of the hub) 12c in which the centrifugal force F1 (see FIG. 14A) acts perpendicularly to the hub surface 12c,

for example, a region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side (the position shown by hatching in FIG. 5), to the position at which the force F2 acting perpendicularly to the hub surface 12c is zero, and in a region positioned between the blades 11.

Reference symbol 314 in FIG. 5 denotes machining tracks for the case where the impeller 310 is manufactured by machining with a ball-end mill, and shows twelve small grooves provided in a region of the hub surface 12c in which the force F2 acting perpendicularly to the hub surface 12c is zero. As described above, the maximum depth and width of these grooves is generally 0.2% of the outside diameter of the impeller. Therefore for an impeller with an outside diameter of 100 mm, the maximum depth and width are approximately 0.2 mm.

[0064]

As shown in FIG. 6A and FIG. 6B, the grooves 313 provided as the boundary layer expansion prevention part, are formed deeper than the machining tracks formed during manufacture of the impeller. That is to say, are formed so that H1 > h1. Here H1 is the maximum depth of the grooves 313, and h1 is the depth of the machining tracks formed during milling of the hub surface 12c.

The maximum depth H1 of the grooves 313 is preferably set to approximately the thickness of the removed boundary layer on the hub surface. More specifically, H1 is preferably between 0.3% and 2.0%, of the outside diameter of the impeller, and most preferably between 0.5% and 2.0%. That is to say, for an impeller of an outside diameter of 100 mm, the maximum depth H1 of the grooves 313 is preferably between 0.3 mm and 2.0 mm, and most preferably between 0.5 mm and 2.0 mm.

[0065]

By providing a plurality of linear grooves 313 in this manner along the surface of the blades 11 in a region on the hub surface 12c in which the centrifugal force F1 acts perpendicularly to the hub surface 12c, the flow flowing along the hub surface 12c close to the hub surface 12c passes over the peak of a groove 313 and flows into the trough of the adjacent groove 313, or passes over the peak of a groove 313 and proceeds diagonally towards the top of the adjacent groove 313, so that turbulence occurs in the flow along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer, or separation of flow can be prevented.

Moreover, since the grooves 313 are formed linearly, the grooves 313 can be readily machined, and manufacturing costs can be kept down.

[0066]

Next, a sixth embodiment of the impeller for a compressor according to the present invention is described using FIG. 7. FIG. 7 is a similar diagram to FIG. 5, being a perspective view of the main parts, omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 320 of the present embodiment differs from the fifth embodiment in that the plan view shape of grooves 323 serving as the boundary layer expansion prevention part, is formed in a wave-shape. Since other elements of the configuration are the same as for the fifth embodiment, a description of these elements of the configuration is omitted here, and only the plan view shape of the grooves 323 is described.

Components in common with the fifth embodiment are labeled with the same reference symbols.

[0067]

The grooves 323 serving as the boundary layer expansion prevention part are wave-shaped in plan view. That is to say, the peaks and troughs are formed in smooth curves in plan view, and these peaks and troughs are formed contiguously. The depth of the grooves 323 is the same as for the grooves 313 in the fifth embodiment, and a description is therefore omitted here.

[0068]

In this manner, by making the plan view shape of the grooves 323 serving as the boundary layer expansion prevention part wave-shaped, the angle between the peak of the grooves 323 and the direction in which the flow passes over the peak of a groove 323 and flows into the trough of the adjacent groove 323, or passes over the peak of a groove 323 and proceeds diagonally towards the top of the adjacent groove 323, can be greater than in the fifth embodiment in some parts. Therefore, strong turbulence occurs at these parts due to the flow of fluid along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer or separation of flow can be prevented.

[0069]

A seventh embodiment of the impeller for a compressor according to the present invention is described using FIG. 8A and FIG. 8B. FIG. 8A is a similar diagram to FIG. 5 and FIG. 7, being a perspective view of the main parts omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 330 of the present embodiment differs from the aforementioned embodiments in that the plan view shape of grooves 333 serving as the boundary layer expansion prevention part is formed in a sawtooth-shape. Since other

elements of the configuration are the same as for the aforementioned embodiments, a description of these elements of the configuration is omitted here, and only the plan view shape of the grooves 333 is described.

Components in common with the aforementioned embodiments are labeled with the same reference symbols.

[0070]

As shown in FIG. 8B, the grooves 333 serving as the boundary layer expansion prevention part of the present embodiment are sawtooth-shaped in plan view. That is to say, the peaks and troughs in plan view are formed by two straight lines, and these peaks and troughs are formed contiguously, and these peaks and troughs are formed so as to be joined by straight lines. The width and depth of the grooves 333 is the same as for the aforementioned embodiments, and a description is therefore omitted here.

[0071]

In this manner, by making the plan view shape of the grooves 333 serving as the boundary layer expansion prevention part sawtooth-shaped, the angle between the peaks of the grooves 333 and the direction in which the flow passes over the peak of a groove 333 and flows into the trough of the adjacent groove 333, or passes over the peak of a groove 333 and proceeds diagonally towards the top of the adjacent groove 333, can be greater than in the

fifth embodiment in some parts, and such parts can be formed in greater numbers than in the sixth embodiment. Therefore strong turbulence occurs at these parts due to the flow of fluid along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer or separation of flow can be prevented.

[0072]

An eighth embodiment of the impeller for a compressor according to the present invention is described using FIG. 9A and FIG. 9B. FIG. 9A is a similar diagram to FIG. 5, FIG. 7, and FIG. 8A, being a perspective view of the main parts omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 340 of the present embodiment differs from the aforementioned embodiments in that grooves 343 serving as the boundary layer expansion prevention part are formed so that they mutually intersect. Since other elements of the configuration are the same as for the aforementioned embodiments, a description of these elements of the configuration is omitted here, and only the grooves 343 are described.

Components in common with the aforementioned embodiments are labeled with the same reference symbols.

[0073]

As shown in FIG. 9B, the grooves 343 serving as the boundary layer expansion prevention part of the present embodiment are formed from a plurality of grooves 343a formed so as to cut diagonally across the flow path formed between the blade 11 and the blade 11 from one side to the other side, and a plurality of grooves 343b formed so as to intersect with the grooves 343a and so as to cut diagonally across the flow path formed between the blade 11 and the blade 11 from the other side to the former side. That is to say, formed so that the grooves 343a extending from bottom-left to top-right, and the grooves 343b extending from bottom-right to top-left mutually intersect.

The solid lines indicating the grooves 343a and 343b in FIG. 9A and FIG. 9B are lines indicating the deepest part of the grooves.

Furthermore, reference symbol 343c indicates the parts remaining after the grooves 343a and 343b have been inscribed. That is to say, the projections where the machining tracks formed at the time of machining of the impeller remain on the apex surface.

The width and depth of the grooves 343a and 343b is the same as for the aforementioned embodiments, and a description is therefore omitted here.

[0074]

In this manner, by forming the grooves 343 serving as the boundary layer expansion prevention part, mutually intersecting, a plurality of projections 343c is formed, and the flow along the hub surface 12c close to the hub surface 12c collides with these projections 343c, or passes over these projections 343c and flows into the troughs of the adjacent grooves 343a and 343b, or passes over the peak of the projection 343c and proceeds diagonally towards the top of the adjacent grooves 343a and 343b, so that turbulence occurs in the flow along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer or separation of flow can be prevented.

[0075]

A ninth embodiment of the impeller for a compressor according to the present invention is described using FIG. 10A and FIG. 10B. FIG. 10A is a similar diagram to FIG. 5, FIG. 7, FIG. 8A, and FIG. 9A, being a perspective view of the main parts omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 350 of the present embodiment differs from the aforementioned embodiments in that grooves 353 serving as the boundary layer expansion prevention part are formed concentrically with the axis of rotation of the impeller 350. Since other elements of the configuration are the

same as for the aforementioned embodiments, a description of these elements of the configuration is omitted here, and only the grooves 353 are described.

Components in common with the aforementioned embodiments are labeled with the same reference symbols.

[0076]

As shown in FIG. 10A, the grooves 353 serving as the boundary layer expansion prevention part of the present embodiment are formed concentrically with the axis of rotation of the impeller 350. That is to say, so as to intersect at right angles radial lines extending from the axis of rotation of the impeller 350 to the outer periphery of the impeller 350. Moreover, FIG. 10B is a cross-sectional view on c-c in FIG. 10A.

The width and depth of the grooves 353 is the same as for the aforementioned embodiments, and a description is therefore omitted here.

[0077]

In this manner, by forming the grooves 353 serving as the boundary layer expansion prevention part, concentrically with the axis of rotation of the impeller 350, the entire flow flowing along the hub surface 12c close to the hub surface 12c passes over the peak of a groove 353 and flows into the trough of the adjacent groove 353, or passes over the peak of a groove 353 and proceeds

diagonally towards the top of the adjacent groove 353, so that strong turbulence occurs in the flow along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer or separation of flow can be prevented.

Furthermore, since the grooves 353 are formed linearly, the grooves 353 can be readily machined, and manufacturing costs can be kept down.

Moreover, the concentric grooves may be formed in a wave-shape as in the sixth embodiment, or in a sawtooth shape as in the seventh embodiment.

[0078]

A tenth embodiment of the impeller for a compressor according to the present invention is described using FIG. 11. FIG. 11 is a similar diagram to FIG. 5, FIG. 7, FIG. 8A, FIG. 9A, and FIG. 10A, being a perspective view of the main parts omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 360 of the present embodiment differs from the aforementioned embodiments in that grooves 363 serving as the boundary layer expansion prevention part are formed over a plurality of regions (three regions 363a, 363b, and 363c in the present embodiment). Since other elements of the configuration are the same as for the aforementioned embodiments, a description of these elements of the

configuration is omitted here, and only the grooves 363 are described.

Components in common with the aforementioned embodiments are labeled with the same reference symbols.

[0079]

As shown in FIG. 11, the grooves 363 serving as the boundary layer expansion prevention part of the present embodiment are fundamentally the same as in the fifth embodiment shown in FIG. 5. However the grooves 363 differ from those in the fifth embodiment in that they are divided into three regions 363a, 363b, and 363c from upstream to downstream. That is to say, a plurality of linear grooves 363 (in FIG. 11, four grooves in region 363a, four grooves in region 363b, and five grooves in region 363c) along the surface of the blade 11 are provided in a region on the hub surface 12c in which the centrifugal force acts perpendicularly to the hub surface 12c, for example, a region from a position approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side (the position shown by hatching in FIG. 5), to the position at which the force F2 acting perpendicularly to the hub surface 12c is zero, and between the blades 11 and 11 of the respective regions.

The width and depth of the grooves 363 is the same as for the aforementioned embodiments, and a description is therefore omitted here.

Furthermore, the effects thus obtained have been described for the fifth embodiment and a description is therefore omitted here.

[0080]

An eleventh embodiment of the impeller for a compressor according to the present invention is described using FIG. 12A and FIG. 12B. FIG. 12A is a similar diagram to FIG. 5, FIG. 7, FIG. 8A, FIG. 9A, FIG. 10A, and FIG. 11, being a perspective view of the main parts omitting approximately 1/4 of the distance from the edge of the impeller inlet to the edge of the outlet, on the inlet side.

An impeller 370 of the present embodiment differs from the aforementioned embodiments in that a plurality of convex parts 373a and a plurality of concave parts (dimples) 373b are provided instead of the grooves previously described as the boundary layer expansion prevention part. Since other elements of the configuration are the same as for the aforementioned embodiments, a description of these elements of the configuration is omitted here, and only the convex parts 373a and concave parts 373b are described.

Components in common with the aforementioned embodiments are labeled with the same reference symbols.

[0081]

As shown in FIG. 12A, the convex parts 373a and concave parts 373b serving as the boundary layer expansion prevention part of the present embodiment are each circular in plan view, and as shown in FIG. 12B, are semi-circular in cross-sectional view.

The diameter and depth of the convex parts 373a and concave parts 373b are similar to in the aforementioned embodiments, and are preferably between 0.3% and 2.0% of the outside diameter of the impeller, and most preferably between 0.5% and 2.0%.

[0082]

By forming the boundary layer expansion prevention part with the plurality of convex parts 373a and the plurality of concave parts 373b, the flow along the hub surface 12c close to the hub surface 12c collides with the convex parts 373a, or passes over the convex parts 373a and flows into the adjacent concave parts 373b, or passes over the convex parts 373a and proceeds diagonally towards the top of the adjacent convex parts 373a or concave part 373b, so that turbulence occurs in the flow along the hub surface 12c close to the hub surface 12c, and expansion of the boundary layer or separation of flow is prevented.

[0083]

The present invention is not only applied to centrifugal compressors, and may also be applied to mixed-flow compressors. However, the mixed-flow compressor differs from the centrifugal compressor in that, since the centrifugal force F1 up to the edge of the impeller outlet acts perpendicularly to the hub surface 12c, when the present invention is applied to a mixed-flow compressor, the region in which the aforementioned boundary layer expansion prevention part is provided extends to the edge of the impeller outlet. That is to say, the boundary layer expansion prevention part is also provided for the part of the grooves 314 shown in FIG. 5, FIG. 7, FIG. 8A, FIG. 9A, FIG. 10A, FIG. 11, and FIG. 12A.

[0084]

Since expansion of the boundary layer, and separation of flow is prevented in the centrifugal compressors and mixed-flow compressors furnished with the aforementioned impeller, losses in the impeller can be reduced, and compression efficiency can be improved.

[0085]

The cross-sectional shape of the grooves 313, 323, 333, 343a, 343b, 353, and 363 is not limited to that shown in FIG. 6B, and for example may also be of a cross-sectional shape as shown in FIG. 13A or FIG. 13B.

That is to say, the cross-section can be a sawtooth-shape as in FIG. 13A in which the trough of a groove is formed as a curve, and the apexes of the trough and peak of the grooves are joined by straight lines, or the initial impeller machining tracks 314 can be left unchanged on the apex of the groove as in FIG. 13B.

[0086]

Furthermore, the present invention is not only applicable to an impeller manufactured by milling, and can also be applied to a cast impeller manufactured by casting. In this case, modifications need only be implemented beforehand to form the aforementioned boundary layer expansion prevention part on the surface of the mold.

[0087]

Moreover, the boundary layer expansion prevention part of the present invention is not limited to the aforementioned grooves, convex parts, concave parts and the like, and similar effects to the aforementioned effects can be obtained by merely having the surface coarser than the hub surface normally used.